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INJECTION CURRENTS IN SEMICONDUCTORS WITH DEEP POLARIZABLE IMPURITY CENTERS

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Translation of "Inzhektsionnyye Toki v Poluprovodnikakh s Polyarizuyemymi Glubokimi Primesnymi Tsentrami," Doklady Akademii Nauk Uzbekskoy SSR, Vol. 30, No. 3, 1973, pp. 28-30.

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16. Abstract

The injection of charge carriers in a semiconductor affords the possibility of modulating ε with current I by changing the saturation of local centers. The function $\varepsilon(I)$ may influence the passage of space-charge limited currents. The distribution of the field and potential in a semiconductor is determined and the volt-ampere characteristic of the specimen is described analytically.

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INJECTION CURRENTS IN SEMICONDUCTORS WITH DEEP POLARIZABLE IMPURITY CENTERS

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The dependence of the dielectric constants of a semiconductor on the extent of filling of deep impurity centers with electrons $N_t f_t = N_t n/(n + n_1)$ is given by the expression [1, 2] /28*

$$\varepsilon = \varepsilon(N_t f_t) = \varepsilon_0 + 4\pi\alpha\varepsilon_0 N_t f_t / \left[\varepsilon_0 - \frac{4}{3}\pi\alpha N_t f_t \right], \tag{1}$$

where ε_0 is the dielectric constant of a crystal without consideration of polarization of impurity centers; α is the polarization of an individual impurity center, reaching values of $\sim 10^{-16}$-10^{-17} CGSE in the case of an acceptor-donor complex impurity.

The injection of charge carriers in a semiconductor, by changing the degree of filling of local centers, results in the possibility of modulation of ε by current I. The function $\varepsilon(I)$ may have an influence on the passage of currents, limited by space charge (CLSC). Assuming that the space charge density is determined by the charge of captured carriers, i.e., $n_1/N_t = \Theta \ll 1$ and $N_t f_t \gg n$, and using the approximate notation $\varepsilon(N_t f_t)$ in the form [3] $\varepsilon = \varepsilon_0(1 + C \cdot N_t f_t)$ when $E(x = 0) = 0$ on the cathode, we find the distribution of field and potential in the specimen

$$x = \frac{\varepsilon_0}{4\pi q}\left[\frac{E}{N_t} + \frac{E^2}{2N_t}\left(\frac{q\mu n_1}{I}\right) + C\left(\frac{I}{q\mu n_1}\right)\cdot \ln\left(1 + \frac{q\mu n_1}{I}E\right)\right], \tag{2}$$

$$V(x) = \frac{\varepsilon_0}{4\pi q}\left\{\frac{E^2}{2N_t} + \frac{E^3}{3N_t}\left(\frac{q\mu n_1}{I}\right) + C\left[\frac{IE}{q\mu n_1} - \left(\frac{I}{q\mu n_1}\right)^2 \ln\left(1 + \frac{q\mu n_1}{I}E\right)\right]\right\}. \tag{3}$$

The volt-ampere characteristic (VAC) of the specimen may be written in implicit form as

*Numbers in the margin indicate pagination in the foreign text.

$$V_T = V(x = w) = \frac{\varepsilon_0}{4\pi q N_t} \left\{ \frac{E^2(w)}{2} + \frac{q\mu n_1}{I} \frac{E^3(w)}{3} + \right.$$
$$\left. + CN_t \left[\frac{I \cdot E(w)}{q\mu n_1} - \left(\frac{I}{q\mu n_1} \right)^2 \ln \left(1 + \frac{q\mu n_1}{I} E(w) \right) \right] \right\}. \quad (4)$$

For sufficiently large currents /29

$$I > I_s = \frac{8\pi q}{\varepsilon} N_t q\mu n_1 \frac{1 - CN_t}{(1 + CN_t)^2} w$$

(4) acquires the form that is typical of the VAC of CLSC at the limit of trap saturation:

$$I = \frac{2}{3} \frac{q\mu n_1}{w} \frac{V_{\mathrm{TFL}}^2}{V_{\mathrm{TFL}} - V} \frac{1 - CN_t}{1 + CN_t}, \quad (5)$$

where $V_{\mathrm{TFL}} = \frac{2\pi q}{\varepsilon_0} N_t w^2$ is the limiting trap saturation voltage. The polarization of the traps does not alter the magnitude V_{TFL}, but leads to a displacement of the interval of rapid growth of I toward smaller currents. When dielectric constant ε is a superlinear function of current, i.e., $\varepsilon(I)/I - (d\varepsilon/dI) > 0$, the VAC of CLSC may have a segment with negative differential resistance (NDR).

Under conditions of drift convergence of double injection currents, when the drift rate of nonequilibrium electron-hole plasma

$$v_a = \frac{\mu_n \mu_p}{\mu_n n + \mu_p p} \left\{ N \left[1 - \frac{1}{qN} \left(\rho - p \frac{d\rho}{dp} \right) \right] + \right.$$
$$\left. + M \left[1 - \left(\frac{n}{M} \frac{\partial M}{\partial n} + \frac{p}{M} \frac{\partial M}{\partial p} \right) \right] \right\} \left(1 - \frac{\partial M}{\partial n} \right)^{-1} \quad (6)$$

is determined by the modulation of the residual space charge $\rho = (4\pi)^{-1} \times (\partial D/\partial x)$ (the "dielectric" mode [4]), the function $\tau(I)$ may lead to violation of the single valuedness of the VAC, which is described inexplicitly by the expression

$$I = \frac{125}{72\pi} \varepsilon(I) \mu_n \mu_p \tau_p V^3/w^5.$$

In particular, in the case of strong reabsorption of recombination emission

$\Phi(I)$ by deep impurities M, the polarization of which is altered strongly as a result of photo excitation, which governs the dependence $\varepsilon = \varepsilon[\Phi(I)]$.

In semiconductors whose dielectric constant has a sufficiently strong temperature dependence $\varepsilon(T)$, under conditions of spontaneous heating of the semiconductor structure by joule heat, additonal possibilities arise for current modulation of ε, resulting in an ambiguous VAC.

The combined analysis of the equation of the VAC $V = V[I, \varepsilon(I)]$ and the heat balance condition $P(T, \Theta) = I \cdot V$ indicates that the sign of differential conductivity

$$\frac{dI}{dV} = \frac{\partial I}{\partial V}\left[\frac{\partial P}{dT} - \frac{\partial}{\partial \varepsilon}(I \cdot V)\frac{d\varepsilon}{dT}\right] \Big/ \left\{\frac{dP}{dT} + \left(\frac{\partial V}{\partial I}\right)^{-1} \times \right.$$
$$\left. \times \left[\frac{\partial V}{\partial \varepsilon} \cdot \frac{\partial}{\partial I}(IV) - \frac{\partial V}{\partial I}\frac{\partial}{\partial \varepsilon}(IV)\right]\frac{d\varepsilon}{dT}\right\} \tag{7}$$

is determined by the character of the function $\varepsilon(T)$.

For the dielectric mode of double injection currents it follows from (7) that if $(d\varepsilon/dT) < 0$, but $|d\varepsilon/dT| > 3\,\frac{\varepsilon}{p}\,(dP/dT)$, then the VAC has a segment with NDC [negative differential conductivity]. But when $d\varepsilon/dT > 0$ and $(d\varepsilon/dT) > \frac{\varepsilon}{p}\,(dP/dT)$, the VAC has a region with NDR. Violation of the single valuedness of the VAC under these conditions is related to the fact that the function $\varepsilon[T(I)]$ causes strong current modulation. /30

For CLSC, correspondingly, when

$$V = \sqrt{\frac{32\pi}{9}\frac{w^3}{\mu}}\sqrt{I/\varepsilon|T(I)|},$$

it follows from (7) that if $\frac{d\varepsilon}{dT} > 0$ and $\frac{d\varepsilon}{dT} > \frac{\varepsilon}{p}\,(dP/dT)$, the VAC exhibits a region with NDR, and when $(d\varepsilon/dT) < 0$, but $|d\varepsilon/dT| > 2\,\frac{\varepsilon}{p}\,(dP/dT)$ the VAC does not have a segment with NDC.

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